EXHIBIT 9

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Testing of Modern Fuel Injection Pumps

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Summary. This paper describes the methods for diagnosing and testing of modern Bosch CP4 fuel injection pump. The tests were conducted in a specialist laboratory dealing with diagnosing, testing and regeneration of fuel injection systems in combustion engines. During the tests, the test object was disassembled into components and then subjected to microscopic analysis. Major causes of the defects in this pump model are specified and presented.

Key words: compression-ignition engine, fuel injection pump, fuel injector, fuel.

INTRODUCTION

Internal combustion piston engines are a primary power source for means of road transport. In recent years, compression-ignition (CI) engines have attracted particular attention owing to their dynamic development. In 1997, a Common Rail (CR) fuel injection system, evolving all the time, was introduced due to the standards referring to exhaust gas toxicity. The main advantage of CR system is division of injected fuel dose by electronic control of fuel injector operation and high fuel injection pressure, reaching at present up to 250 MPa. The intention is that the rate of modern engine fuel supply system development meets the rigorous standards through such an organisation of the process of air-fuel mixture combustion that as little toxic substances as possible are emitted to the air by the engine at the lowest possible fuel consumption, preserving its basic operating parameters, such as power and torque.

COMMON RAIL SYSTEM CHARACTERISTICS

Modern fuel injection systems with a common rail high pressure collector have replaced conventional systems with high pressure pipe and pipe-less systems, called pump-line-injectors [1]. The control and repeatability of such parameters as fuel dose, fuel injection pressure and injection angle timing device have led to the separation of fuel pumping function from the control of injection parameters. A high pressure pump has been introduced, with the function to generate pressure up to 200 MPa in the fuel rail [6]. Electronically controlled fuel injectors execute the injection of a set fuel dose. The common rail high pressure system is composed of the following elements: an injection pump, a fuel rail accumulator and fuel injectors [5].

The function of high pressure pump is to generate and maintain pressure ranging from 25 to about 200 MPa in the system. Usually, they are radial-flow positive displacement pumps driven from an engine camshaft. Only two common rail distributor pumps are known, manufactured by Delphi and Denso [8]. Modern injection pumps are characterised by very high efficiency of 95%. If the pump efficiency drops below 80%, it should undergo regeneration. A fuel delivery regulator, high pressure regulator and pressure sensor can be found on the injection pump, depending on the system design.

The function of fuel rail is to maintain the pressure value and distribute fuel to fuel injectors. Its capacity is calculated so that pressure oscillations during the injection and pumping stage are minimised. A pressure regulator or sensor can be found on the fuel rail, or a release valve in some designs [15, 16, 20].

Fuel injectors are responsible for accurate fuel atomisation and distribution in the engine combustion chamber. In the common rail fuel injection systems, the engine controller and fuel injector are responsible for the quantity of injected fuel [2]. Injector malfunctions start with changes in the volume of injection doses and return doses, being called the overflow volumes. The overflow volume is a discharge of injector's working fluid and its values at the full load should not exceed 40 mm^3/h (needle travel lift). Modern fuel injectors are able to apply initial fuel injection, main fuel injection

and extra fuel injection. In modern design solutions, solenoid and piezoelectric fuel injectors are applied.

Application of the electronic control of fuel injector operation in the common rail fuel injection system enables the precise metering of a fuel dose with large repeatability. It is possible to control several fuel injection doses through which the process of fuel combustion in compression-ignition engine has been improved [2, 3, 4, 9, 10, 11, 12, 13, 14, 17, 18, 19]. Figure 1 presents a simplified construction of the common rail fuel injection system.

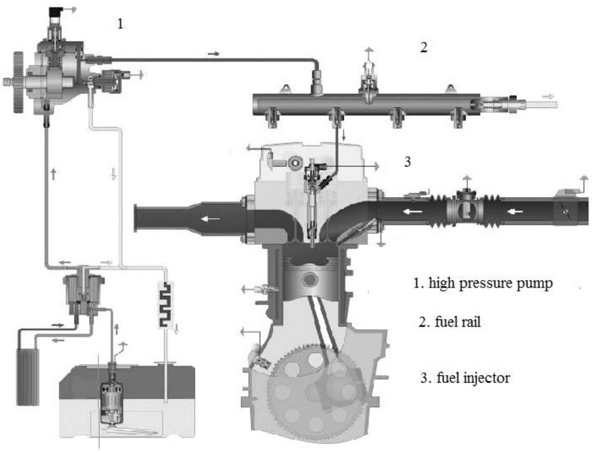

Fig. 1. Simplified construction of the common rail fuel injection system

STUDY OBJECTIVE AND TEST SCHEME

The aim of this study was to analyse the technical condition of Bosch CP4 high pressure pump and the causes of its defects. The tested fuel injection pomp tested, with the catalogue number 0445010506, was installed in a vehicle with the mileage of about 150 thousand kilometres. The vehicle was also equipped with second-generation Bosch piezoelectric fuel injectors, with the catalogue number 0445116001.

Laboratory tests were conducted according to the following scheme:

– testing of high pressure pump on a test bench,
– disassembly of high pressure pump into components,
– analysis of individual high pressure pump units under a microscope,
– determination of the causes of defects in the tested object,
– testing of components which could be damaged as a result of pump damage.

PRESENTATION OF TEST OBJECT AND TEST STAND

The test object was a Bosch CP4 fuel injection pump with the catalogue number 0445010506. Figure 2 presents the tested fuel injection pump being.

Laboratory tests were conducted using a specialist stereoscopic microscope FL 150/70. The testing consisted in analysing the damaged pump units. Due to the lack of repair technology and possibility to test the fuel injection pump on a test bench, its efficiency was not examined. Figure 3 presents the stereoscopic microscope used for testing.

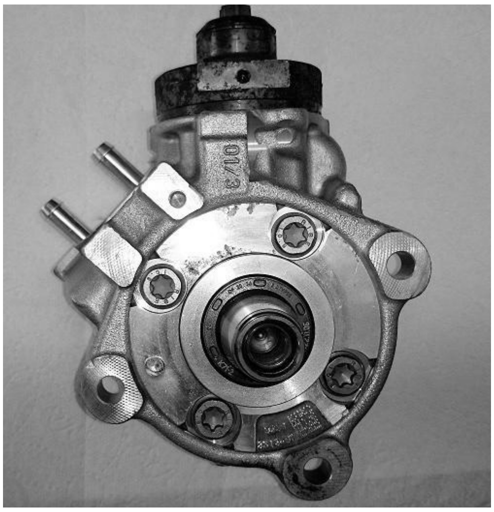

Fig. 2. Fuel injection pump Bosch CP4

Fig. 3. Stereoscopic microscope FL 150/70

LABORATORY TESTS

The first stage of laboratory tests was disassembly of the tested fuel injection pump tested into components. Figure 4 presents the fuel injection pump components.

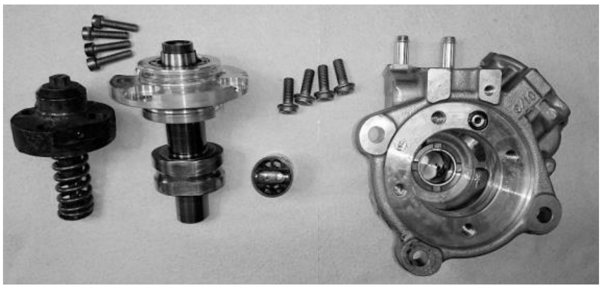

Fig. 4. The tested fuel injection pump disassembled into components

Fuel injection pump Bosch CP4 is composed of: a drive shaft, a roller in the holder and a plunger pumping section. The most durable component of the tested fuel injection pump tested is its plunger pumping section. The roller with its holder is in the pump body. A defect of this component is lack of stabilisation, which causes that the whole roller can rotate 360° in the pump body (Fig. 5).

Fig. 5. A roller in the pump body in a faulty position

If the roller starts rotating around its own axis during the pump operation, it is no longer possible for it to return to its original position. Then, it starts destroying a cam on the pump drive shaft. As a result of friction on a cam and a roller, metal filings are generated, fouling and destroying the whole fuel supply system. Figure 6 presents a faulty position of the roller in relation to a drive shaft cam, with evidence of considerable destruction being visible on both components.

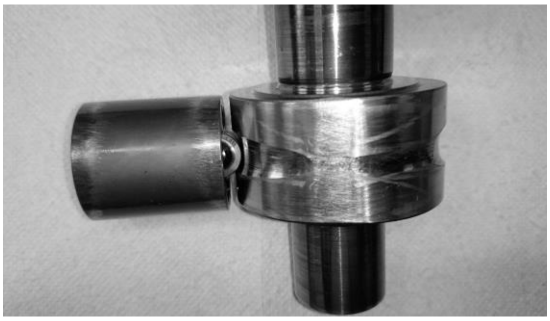

Fig. 6. Faulty position of a roller in relation to a drive shaft cam

Metal filings are deposited on the body of fuel injection pump, from where they are being flushed to the fuel supply system. The low pressure system, together with the fuel tank, is being fouled, as well as the high pressure system (CR rail, fuel injectors, pressure regulator and sensor). Over time, a seizure in fuel injectors and pressure regulator takes place. Figure 7 presents a place of metal filings collection on the fuel injection pump body.

Fig. 7. Place of metal filings collection in the pump body

Figure 8 presents metal filings being found in the fouled fuel. Such a large amount of them indicates that the whole fuel supply system must be absolutely cleaned and the fuel tank replaced.

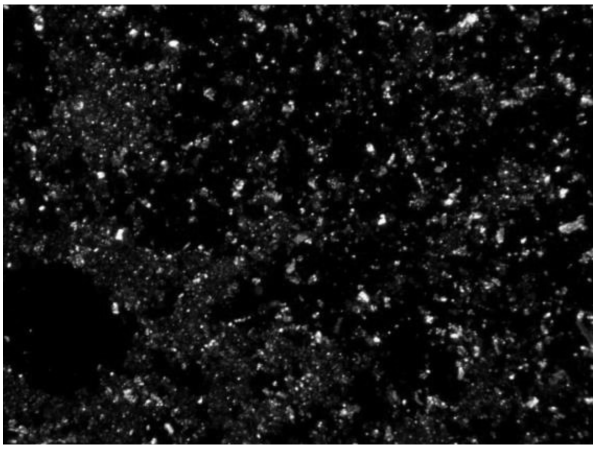

Fig. 8. Fuel fouled by metal filings from high pressure pump

Figure 9 presents a high pressure regulator fouled by metal filings. Its function is to maintain the pressure set by the engine controller in the fuel supply system.

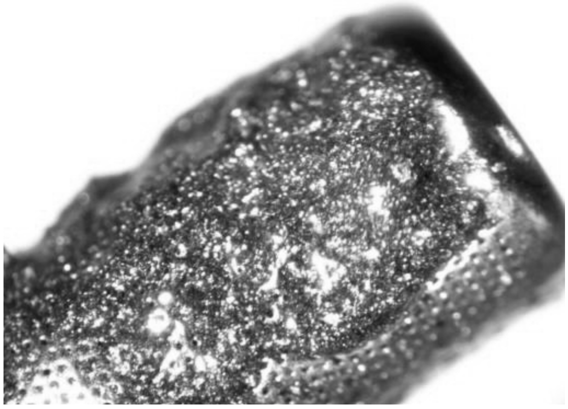

Fig. 9. High pressure regulator fouled by metal filings in fuel

CONCLUSIONS

The analysis of the conducted tests demonstrates that one of the defects in the fuel supply system is malfunction related to fuel injection pumps. The tested fuel injection pump tested belongs to the latest generation of pumps. A deficient component of the tested object is the roller assembly rotating around its own axis in the fuel injection pump housing. As a result of the pump operation and the fouling found in fuel, its position in relation to the drive shaft cam can be changed. As a result of its rotation, the roller stops fulfilling its function. Because of the friction on the cam, it starts furrowing metal on its surface. Then, metal filings are being developed which foul the whole fuel supply system. These metal filings get everywhere with fuel: to fuel tank, fuel filter, CR rail, pressure regulator and sensor, as well as to fuel injectors, destroying them. One of the ways to avoid this defect in CP4 pump is to frequently replace fuel filters and perform periodic cleaning of the whole engine fuel supply system.

REFERENCES

1. **Abramek K. F. 2010:** The modelling of heat exchange between the piston – rings – cylinder assembly elements. TEKA Commission of Motorization and Energetics in Agriculture. Volume X. PAN Lublin.
2. **Dziubiński M., Czarnigowski J. 2011:** Modelling and verification failures of a combustion engine injection system. TEKA Commission of Motorization and Energetics in Agriculture. Volume XIC. PAN Lublin.
3. **Gołębiewski W., Stoeck T 2011.:** Traction qualities of a motor car Fiat Panda equipped with a 1,3 16V Multijet engine. TEKA Commission of Motorization and Energetics in Agriculture. Volume XIC. PAN Lublin.
4. **Gołębiewski W., Stoeck T 2013.:** Relationships between Common Rail accumulator pressure and vehicle traction properties. TEKA Commission of Motorization and Energetics in Agriculture. Volume XIII. No 1. PAN Lublin.
5. **Idzior M. 2013:** Research and analysis of the influence of the injection pressure on spraying fuel in the chamber about the fixed volume. Combustion engines. 2013, 154(3).
6. **Kirichenko I., Strilets O., Koshovy M. 2012:** Piezo actuators injector of Common Rail fuel injection system. TEKA Commission of Motorization and Energetics in Agriculture. Volume XII. No 3. PAN Lublin.
7. **Kozak M. 2011:** An aplication of butanol as a Diesel fuel component and its influence on exhaust emissions. TEKA Commission of Motorization and Energetics in Agriculture. Volume XIC. PAN Lublin.
8. **Mysłowski J. 2011:** Negative impact of motorization on the natural environment. TEKA Commission of Motorization and Energetics in Agriculture. Volume XIC. PAN Lublin.
9. **Osipowicz T., Abramek K. 2014:** Catalytic treatment in Diesel engine injectors. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2014. 16 (1): 22–28.
10. **Osipowicz T., Kowalek S. 2014:** Physical Phenomena Occuring in a Diesel injector Nozzle. TEKA Commission of Motorization and Energetics in Agriculture. Volume XIV. No 3. PAN Lublin.
11. **Osipowicz T., Kowalek S. 2014:** Evaluation of Modern Diesel Engine Fuel Injectors. TEKA Commission of Motorization and Energetics in Agriculture. Volume XIV. No 3. PAN Lublin.
12. **Osipowicz T. Stoeck T. 2013:** Repair contemporary Diesel engine injectors. Autobusy, Technika, Eksploatacja, Systemy Transportowe nr 10.
13. **Osipowicz T. Stoeck T. 2013:** The influence of neutral dosage on technical work Common Rail Diesel engine. Autobusy, Technika, Eksploatacja, Systemy Transportowe nr 10.
14. **Piątkowski P. 2012:** The impact of intake canal geometry on kinematics of load in combustion chamber. TEKA Commission of Motorization and Energetics in Agriculture. Volume XII. No 1. PAN Lublin.
15. **Reksa M., Sroka Z.J. 2013:** The impact of fuel properties on shape of injected fuel spray. Combustion Engines. 2013, 154(3).
16. **Stanik W., Jakóbiec J., Wądrzyk M. 2013:** Design factors affecting the formation of the air-fuel mixture and the process of combustion in compression ignition engines. Combustion Engines. 2013, 154(3).
17. **Stoeck T. Osipowicz T. 2013:** Issue of verification and repairing Common Rail Diesel Delphi injectors. Autobusy, Technika, Eksploatacja, Systemy Transportowe nr 10.
18. **Stoeck T. Osipowicz T. 2013:** The analysis of damages and running down of Bosch Common Rail injectors. Autobusy, Technika, Eksploatacja, Systemy Transportowe nr 10.
19. **Stoeck T. Osipowicz T. 2013:** Analysis of damages Common Rail injectors using in Diesel engines commercial vehicles. Logistyka. Instytut Logistyki i Magazynowania nr 6.
20. **Walaszyk A., Busz W. 2013:** Application of optical method for the analysis delay between control injector coil and beginning of the fuel injection. Combustion Engines. 2013, 154(3).

BADANIE WSPÓŁCZESNYCH POMP WTRYSKOWYCH

Streszczenie. Artykuł opisuje sposoby diagnozowania i badania współczesnej pompy wtryskowej Bosch CP4. Badania zostały przeprowadzone w specjalistycznym laboratorium zajmującym się diagnozowaniem, badaniem i regeneracją układów wtryskowych w silnikach spalinowych. Podczas badań obiekt został zdemontowany na elementy składowe następnie poddany analizie mikroskopowej. Zostały wyszczególnione i przedstawione główne przyczyny awarii tego modelu pompy.

Słowa kluczowe: silnik o zapłonie samoczynnym, pompa wtryskowa, wtryskiwacz paliwa, paliwo.